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# The accuracy of different dental impression techniques for implant-supported dental prostheses: A systematic review and meta-analysis

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## Abstract

**Aim:** This systematic review and meta-analysis were conducted to assess and compare the accuracy of conventional and digital implant impressions. The review was registered on the PROSPERO register (registration number: CRD42016050730).

**Material and Methods:** A systematic literature search was conducted adhering to PRISMA guidelines to identify studies on implant impressions published between 2012 and 2017. Experimental and clinical studies at all levels of evidence published in peer-reviewed journals were included, excluding expert opinions. Data extraction was performed along defined parameters for studied specimens, digital and conventional impression specifications and outcome assessment.

**Results:** Seventy-nine studies were included for the systematic review, thereof 77 experimental studies, one RCT and one retrospective study. The study setting was in vitro for most of the included studies (75 studies) and in vivo for four studies. Accuracy of conventional impressions was examined in 59 studies, whereas digital impressions were examined in 11 studies. Nine studies compared the accuracy of conventional and digital implant impressions. Reported measurements for the accuracy include the following: (a) linear and angular deviations between reference models and test models fabricated with each impression technique; (b) three-dimensional deviations between impression posts and scan bodies respectively; and (c) fit of implant-supported frameworks, assessed by measuring marginal discrepancy along implant abutments.) Meta-analysis was performed of 62 studies. The results of conventional and digital implant impressions exhibited high values for heterogeneity.

**Conclusions:** The available data for accuracy of digital and conventional implant impressions have a low evidence level and do not include sufficient data on in vivo application to derive clinical recommendations.

## KEYWORDS

computer-aided design, digital implant impressions, implant impressions, intraoral scanning

## 1 | INTRODUCTION

This systematic review examines current literature on the accuracy of conventional and digital implant impression methods published between 2012 and 2017. Conventional and digital implant impressions transfer the intraoral position of dental implants to a working cast. Digital impressions use optical methods to acquire implant positions and display them in a virtual model. Conventional methods use impression material and impressions copings to transfer implant positions to a stone cast with implant analogs in original implant positions.

The position of dental implants is recorded and transferred to a working stone cast for the manufacturing of implant-supported prosthesis (Lee, So, Hochstedler, & Ercoli, 2008). The correct transfer of each implant position in relation to neighboring implants or teeth is paramount for the design and fit of implant-supported prosthesis and therefore for long-term success of implant therapy avoiding mechanical and biological complications (Kunavisarut, Lang, Stoner, & Felton, 2002; Sahin, Cehreli, & Yalcin, 2002; Wang, Leu, Wang, & Lin, 2002).

The conventional workflow for dental implant impressions involves screw-retained impression copings that are attached to the implant and impression trays loaded with impression material. Impression copings are either retained in the cured impression material (pick-up method) (Di Fiore et al., 2015; Papaspyridakos et al., 2012; Pera, Pesce, Bevilacqua, Setti, & Menini, 2016) or remain in the implants and are repositioned in the respective regions in the impression after it is removed from the mouth (transfer method) (Calesini et al., 2014; Ibrahim & Ghuneim, 2013). Replacement of transfer copings after removal of the impression from the mouth may be facilitated by plastic caps seated on transfer copings that are retained in the impression (Abdel-Azim, Zandinejad, Elathamna, Lin, & Morton, 2014; Gökçen-Rohlig, Ongül, Sancakli, & Sermet, 2014).

The pick-up method is performed with open impression trays. To remove the impression with copings, the screw retention must be loosened. This is achieved through holes in the impression tray that are located on top of the impression coping. The transfer method is performed with closed impression trays, as no access to the screw-retained copings is required. Pick-up impression copings are frequently splinted to each other with acrylic resin or other materials or structures (bars, straws or dental floss) before adding impression material (Martínez-Rus, García, Santamaría, Özcan, & Pradies, 2013; Ongül, Gökçen-Röhlig, Şermet, & Keskin, 2012; Zen et al., 2015). The rigid connection of multiple impression copings is applied to avoid movement of impression copings in the elastic impression material. A higher impression accuracy with splinted impression copings compared to nonsplinted copings has been reported (Al Quran, Rashdan, Abu Zomar, & Weiner, 2012; Filho, Mazaro, Vedovatto, Assuncao, & dos Santos, 2009; Hariharan, Shankar, Rajan, Baig, & Azhagarasan, 2010; Heidari, Fallahi, & Izadi, 2016; Zen et al., 2015).

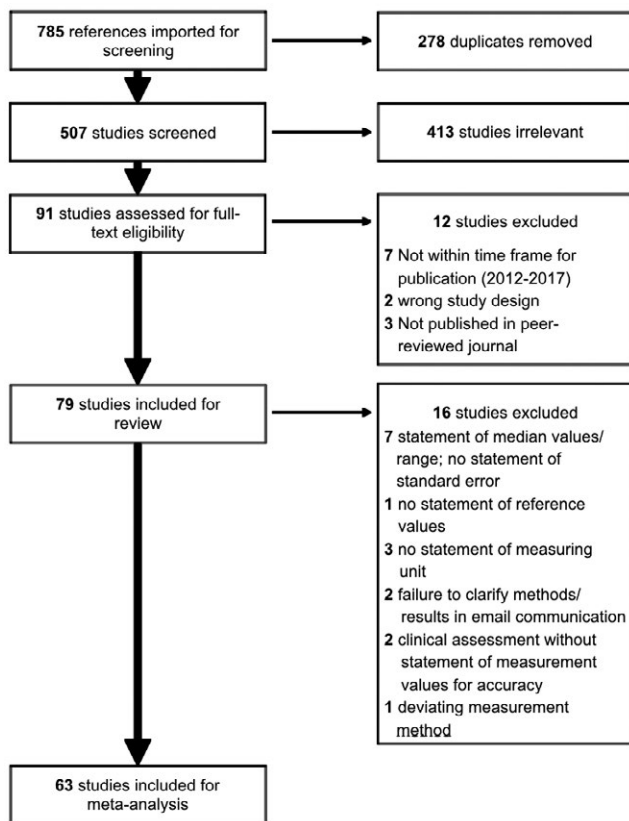
Digital implant impressions are a new method for the acquisition of implant positions and may replace conventional implant impressions and stone cast production (Amin et al., 2016; Karl, Graef,

Schubinski, & Taylor, 2012; Papaspyridakos et al., 2016). With digital implant impressions, the conventional workflow for the manufacturing of implant-supported prosthesis is avoided and the utilization of CAD/CAM technology is initiated. Digital impression summarizes multiple optical technologies to attain the position of dental implants in a virtual model (Giménez, Özcan, Martínez-Rus, & Pradies, 2014, 2015a,b; Giménez, Pradies, Martínez-Rus, & Özcan, 2015). Analog to conventional implant impressions, scan bodies are connected to dental implants, creating an accessible surface for optical acquisition (Flügge, Att, Metzger, & Nelson, 2017). The position of implant scan bodies within the dental arch is recorded with intraoral scanning devices and results in a virtual stone cast displaying the scan bodies. With the knowledge of scan body dimensions, the spatial position of each implant connected to a scan body is reconstructed. Based on the virtual position of implants, prostheses are virtually designed and may be manufactured using CAM technology (Aktas, Özcan, Aydin, Şahin, & Akça, 2014; Katsoulis et al., 2013). Depending on the optical scanning technology, a titanium oxide powder may be required on intraoral surfaces (Abdel-Azim et al., 2014; Karl et al., 2012; Vandeweghe, Vervack, Dierens, & De Bruyn, 2017).

To take advantage of virtual design tools and novel computer-aided production processes of implant-supported frameworks, stone cast with implant analogs may as well be scanned using optical scanners. In this case, a conventional implant impression is used to transfer the implant position from the mouth to a stone cast and scan bodies are connected to dental implant analogs in the model. The model is placed in a model scanner and optically recorded (Aktas et al., 2014; Flügge et al., 2017; Katsoulis et al., 2013; Stimmelmayer, Guth, Erdelt, Edelhoff, & Beuer, 2011).

The transfer of implant positions with conventional, intraoral optical or extraoral optical methods is the starting point for the production process of implant-supported prosthesis. Multiple studies examined and compared the accuracy of different implant impression techniques. However, intraoral implant positions must be transferred to an extraoral reference model for the assessment of the accuracy of intraoral impressions. The technique with the least assumed error is used to create a reference model and novel methods are compared with the previously created reference model (Andriessen, Rijkens, van der Meer, & Wismeijer, 2014; Papaspyridakos et al., 2016). Therefore, accuracy assessment of intraoral impressions is limited to the comparison of different techniques. The term accuracy refers to the trueness, describing the closeness of a measurement to the actual value, and by the precision, describing the closeness of multiple measurement results.

This review examines studies on the accuracy and on the precision of different digital impressions versus conventional implant impressions techniques. Digital impression techniques include direct intraoral scanning using intraoral scanning devices, extraoral scanning of stone casts using either intraoral scanning devices or extraoral scanning of stone casts using dental laboratory scanners.



**FIGURE 1** Flowchart of the search process adhering to PRISMA

## 2 | MATERIAL AND METHODS

This systematic literature review was performed adhering to Transparent Reporting of Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Figure 1). The review was registered on the PROSPERO register (registration number: CRD4201605 0730).

### 2.1 | Pico question

The focused PICO (Population, Intervention, Comparison, Outcome) question was: "Are digital impressions as accurate as conventional impressions for dental implant restorations?"

### 2.2 | Search strategy

The systematic search was conducted on PubMed MEDLINE, CENTRAL, EMBASE and Google Scholar databases using the (MeSH) keywords relevant for the focused question. The search was limited to a time frame of recent 5 years from January 1, 2012, to the date of search (March 1, 2017). Additional hand searching was performed of the following journals: Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, Implant Dentistry, International Journal of Oral and Maxillofacial Implants, Journal of Clinical Periodontology, Journal

of Computerized Dentistry, Journal of Implantology and Journal of Periodontology.

The used search terms were as follows: (((dental implants [MeSH Terms]) OR dental implant\*)) AND ((dental impression technique [MeSH Terms]) OR dental impression technique\*)) AND (((dimensional measurement accuracy [MeSH Terms]) OR impression accuracy) OR accuracy) OR dimensional measurement accuracy). The search strategy and terms were modified in accordance with the searched database.

Inclusion criteria were defined as follows:

- Studies at all levels of evidence, except expert opinion
- Experimental and clinical studies
- Case reports with at least five patients
- In vitro and in vivo studies
- Publications in peer-reviewed journals

Studies with the following characteristics were excluded:

- Multiple publications based on the same patient population
- Animal studies

### 2.3 | Study selection and quality assessment

Most included studies (78 of 79 studies) were neither randomized/nonrandomized controlled trials nor controlled clinical trials. Therefore, quality assessment according to PRISMA was not performed.

### 2.4 | Data extraction

Two reviewers (TF, PW) independently screened titles and abstracts of all studies retrieved from the above-mentioned search strategy and voted for inclusion or exclusion, respectively. Conflicts were resolved in discussion with a third reviewer (BG). Subsequently, full-text screening was performed and studies were excluded when failed to meet the inclusion criteria or fall into the category of exclusion criteria. Six studies not published in the regarded time frame were excluded, two case reports were excluded because of wrong study designs, and two studies not published in peer-reviewed journals were excluded.

The following data were extracted from each study:

- Study designs: Randomized/nonrandomized controlled trial, retrospective study, case series, experimental study
- Study settings: in vivo, in vitro
- Impression technologies: digital, conventional
- Tooth status in the implant impression-taking region: single-unit case, partially edentulous or completely edentulous arch, number and distribution of implants.
- Angulation and vertical position of implants
- Implant systems and types of implant–abutment interface
- Operator experience

- Impression levels: implant level, abutment level
- Digital impressions
  - Optical scanning devices
  - Scan body manufacturers and features
  - Splinting or nonsplinting
  - Powder application
- Conventional impressions
  - Impression tray designs
  - Impression coping manufacturers and features
  - Impression material
- Assessment methods
  - Linear deviation
  - Angular deviation
  - 3D surface deviation
  - Marginal discrepancy (of restorations)
- Outcome reporting
  - Accuracy
  - Precision
  - Fit (of restorations)

## 2.5 | Meta-analysis

Random-effect models were used for meta-analysis of each subgroup to compare results of conventional and digital implant impression systems using Stata software (Stata 14.2, StataCorp).

## 3 | RESULTS

Seventy-nine studies were included in this systematic review. The study design was assessed and resulted in three groups: 77 experimental studies, one retrospective study (Perez-Davidi, Levit, Walter, Eilat, & Rosenfeld, 2016) and one randomized controlled clinical trial (Pozzi, Tallarico, Mangani, & Barlattani, 2013) (Table 1).

Most studies were performed in vitro using experimental stone, metal or resin models with implants or laboratory analogs, respectively (75 studies). One study examined digital impressions in vitro using formalin-conserved human mandibles (Corominas-Delgado et al., 2015). One randomized controlled clinical trial (Pozzi et al., 2013), one retrospective study (Perez-Davidi et al., 2016) and two experimental studies (Andriessen et al., 2014; Papaspyridakos et al., 2012) were performed in vivo (Table 2).

Digital impressions were studied in 11 studies, whereas 59 studies focused on conventional impressions. Digital and conventional impressions were directly compared in nine studies (Table 3).

Impression techniques were studied in various edentulous status. Sixty-three studies examined completely edentulous arches with two implants (13 studies), three implants (one study), four implants (27 studies), five implants (three studies) and six implants (18 studies), respectively. Twelve studies with partially edentulous arches had specimens with one implant (one study), two implants (eight studies) and with two and five implants, respectively (one study). Two studies included partially and completely edentulous arches (Sabouhi,

**TABLE 1** Summary of study designs for all included studies

Study design	Number of studies
RCT	1
Nonrandomized controlled clinical trial	–
Experimental study	77
Retrospective study	1
Case series	–

**TABLE 2** Summary of study settings

Study setting	Number of studies
In vitro	75
In vivo	4

**TABLE 3** Summary of impression technologies applied in included studies

Technology	Number of studies
Digital impression	11
Digital vs. conventional impression	9
Conventional impression	59

Bajoghli, & Abolhasani, 2015; Sabouhi, Bajoghli, Dakhilalian, Beygi, & Abolhasani, 2016), one study included completely edentulous arches and a single-unit restoration (Abdel-Azim et al., 2014). Two studies assessed a single unit (Aktas et al., 2014; Lee, Betensky, Gianneschi, & Gallucci, 2015). One study included patients with various indications for implant therapy (Perez-Davidi et al., 2016).

### 3.1 | Angulation and vertical position of implants

Out of 79 studies, 18 studies evaluated impression accuracy of parallel implants; 11 studies used specimens with angulated implants, 24 studies did not state angulation of implants and two studies had specimens with a single implant. Twenty-four studies focused on the comparison of impression accuracy for parallel and angulated implants. Regardless of various impression techniques, conventional implant impressions of angulated implants were significantly less accurate compared to parallel implants (Akalin, Ozkan, & Ekerim, 2013; Heidari et al., 2016; Kurtulmus-Yilmaz, Ozan, Ozcelik, & Yagiz, 2014; Mpikos et al., 2012; Ng, Tan, Teoh, Cheng, & Nicholls, 2014; Shim, Ryu, Shin, & Lee, 2015; Siadat, Alikhasi, Beyabanaki, & Rahimian, 2016; Tsagkalidis, Tortopidis, Mpikos, Kaisarlis, & Koidis, 2015). However, other studies reported that different implant angulations showed no significant difference in impression accuracy (Calesini et al., 2014; Ehsani, Siadat, & Alikhasi, 2013; Hazboun, 2013; Howell, McGlumphy, Drago, & Knapik, 2013; Lin, Harris, Elathamna, Abdel-Azim, & Morton, 2015).

Likewise, digital impressions of angulated implants did not show a significantly different impression accuracy compared to parallel implants (Giménez et al., 2014, 2015a,b; Giménez, Pradies et al., 2015; Papaspyridakos et al., 2012). Lin et al. (2015) observed higher impression accuracy of digital implant impressions with implant divergence when comparing with parallel implants.

**TABLE 4** Summary of studies of digital implant impressions [In PDF format, this table is best viewed in two-page mode]

Author	Study type	Specimen	No. of implants	Angulation of implants	Vertical position of implants	Implant System	Fixture	Operator
Aktas et al. (2014)	In vitro	Single unit	1	-	Not stated	Straumann TL	Implant	Not stated
Corominas-Delgado et al. (2015)	Ex vivo	Edentulous	6	Not stated	Not stated	Adin Touareg	Implant	Not stated
Flügge et al. (2017)	In vitro	Partially edentulous	2	Not stated	Not stated	Camlog, Straumann BL/TL	Analog	Not stated
Flügge et al., 2016;	In vitro	Partially edentulous	2; 5	Not stated	Not stated	Straumann BL/TL	Analog	Not stated
Giménez et al. (2014)	In vitro	Edentulous	6	12, 22, 17, 27:parallel 15, 25: 30°	12: 4 mm sub; 22: 2 mm sub; 15, 25, 17, 27: equigingival	Certain 4, Biomet 3i	Implant	Experienced Inexperienced
Giménez et al. (2015a)	In vitro	Edentulous	6	12, 22, 17, 27:parallel 15, 25: 30°	12: 4 mm sub; 22: 2 mm sub; 15, 25, 17, 27: equigingival	Certain 4, Biomet 3i	Implant	Experienced Inexperienced
Giménez et al. (2015b)	In vitro	Edentulous	6	12, 22, 17, 27:parallel 15, 25: 30°	12: 4 mm sub; 22: 2 mm sub; 15, 25, 17, 27: equigingival	Certain 4, Biomet 3i	Implant	Experienced Inexperienced
Giménez, Pradiés et al., 2015	In vitro	Edentulous	6	12, 22, 17, 27:parallel 15, 25: 30°	12: 4 mm sub; 22: 2 mm sub; 15, 25, 17, 27: equigingival	Certain 4, Biomet 3i	Implant	Experienced Inexperienced
Katsoulis et al. (2013)	In vitro	Edentulous	6	11, 13, 21, 23: parallel 15, 25: 10°	Not stated	Nobel Replace	Analog	Not stated
Stimmelmayer, Erdelt et al., 2012; Stimmelmayer, Güth et al., 2012	In vitro	Edentulous	4	Not stated	Not stated	Camlog	Implant/ analog	Not stated
Vandeweghe et al. (2017)	In vitro	Edentulous	6	46–44:0.6° 44–42: 1.7° 42–43:4.6° 32–34: 4.8° 34–36:4.2°	Not stated	IBT Southern Implants	Implant	Not stated

The majority of studies of conventional implant impressions (55 studies) did not examine the vertical position of implants. The equigingival (BalaMurugan & Manimaran, 2013) or supragingival (Sabouhi et al., 2015, 2016) placement of implants was stated, however, not evaluated for the impression accuracy. Implants were placed at depths of 0, 1 and 3 mm and examined along with other specifications for conventional implant impressions (Martínez-Rus et al., 2013). However, the effect of depth was not evaluated independently from other factors.

Four studies using digital impressions examined the vertical position of implants (equigingivally; 2 and 4 mm subgingivally). The implant depth did not affect impression accuracy in any of these studies (Giménez et al., 2014, 2015a,b; Giménez, Pradiés et al., 2015).

### 3.2 | Operator experience

Few studies of conventional implant impression accuracy stated experience of operators (Ghahremanloo, Seifi, Ghanbarzade, Abrisham, & Javan, 2017; Gupta, Narayan, & Balakrishnan, 2017; Perez-Davidi et al., 2016). In a clinical study, impressions were performed by senior dentists and residents, respectively. The accuracy of each impression technique was evaluated by assessing the fit of implant-supported frameworks in periapical radiographs. There was no difference in fit between three different impression techniques when performed by senior dentists. However, ill-fitting frameworks were observed significantly more often when manufactured with an impression technique involving intraoral splinting of copings to impression trays performed by residents (Perez-Davidi et al., 2016).

**TABLE 4** (additional columns)

Impression level	Optical scanning device	Scan body manufacturer	Scan body features	Splinting	Powder	Outcomes
Implant level	inEos, inLab, Cerec 3D	Straumann synOcta abutment	synOcta abutment	-	Powder	Significant differences in marginal gaps for inEos, CEREC and inLab scanners
Implant level	CBCT	LOC-i	Screw retained	Not splinted	No powder	CBCT valid for impression-taking for full-mouth rehabilitations with implants
Implant level	D250	Camlog, Straumann	Cylindrical, screw retained	Not splinted	No powder	Precision of extraoral scanning is dependent on scan body surface design and geometry
Implant level	iTero, Trios, TrueDef	Straumann	Cylindrical, screw retained	Not splinted	Powder/no powder	Digital full-arch impressions less precise than quadrant impressions
Implant level	iTero	Createch	Cylindrical, screw retained	Not splinted	No powder	Quadrant scanning more accurate than full-arch scanning; inexperienced more accurate than experienced operator
Implant level	Cerec AC Bluecam (Version 4.0)	Createch	Cylindrical, screw retained	Not splinted	No powder	Quadrant scanning more accurate than full-arch scanning
Implant level	Lava COS	Createch	Cylindrical, screw retained	Not splinted	Powder	No significant influence of operator experience, implant depths and angulation
Implant level	3D Progress, ZFX Intrascan	Createch	Cylindrical, screw retained	Not splinted	No powder	Scanning systems not suitable for multi-implant impressions
Implant level	I Metric 3D; Nobel Procera	Nobel Procera	Cylindrical, screw retained	Not splinted	Powder/no powder	High precision of fit of CAD/CAM titanium bars from photogrammetric and laser scanning
Implant level	Everest	Camlog	Cylindrical, screw retained	Not splinted	Powder/no powder	Scan body fit more reproducible on lab analogs compared to original implants
Implant level	Lava COS, True Def, Omnicam, Trios	Proscan	Cylindrical, screw retained	Not splinted	Powder/no powder	Highest accuracy for TrueDef and Trios; Lava COS not suitable for multi-implant and full-arch scanning

Four studies of digital implant impressions techniques examined the influence of operator experience with digital impression techniques on impression accuracy. A significant difference was found between experienced and inexperienced operators with one inexperienced operator yielding significantly lower impression accuracy compared to two experienced operators and one other inexperienced operator (Giménez et al., 2014). However, in another study, inexperienced operators performed significantly better for impression accuracy compared to experienced operators with another intraoral scanning device (Giménez et al., 2015a,b; Giménez, Pradies et al., 2015). In a further study, a significant higher accuracy of digital impression by experienced operators was documented in the beginning of the scanning series. After completing all consecutive scans, the difference between experienced and inexperienced operators was not significant anymore

(Giménez et al., 2015a,b; Giménez, Pradies et al., 2015). The use of two other scanning devices did not result in significant differences for digital impression accuracy for experienced and inexperienced operators (Giménez et al., 2015a,b; Giménez, Pradies et al., 2015).

### 3.3 | Optical scanning devices

Multiple optical scanners for direct intraoral optical scanning and for extraoral scanning of stone casts were examined in the included studies.

Several studies studied the accuracy of extraoral optical scanners with different technologies, such as blue and white light scanners (inEos, CEREC inLab, Sirona Dental Systems, Germany) and (Everest Scan Pro KaVo, Germany) (Aktas et al., 2014; Stimmelmayer, Erdelt, Guth, Happe, &



**TABLE 5** Summary of studies comparing digital and conventional implant impressions [In PDF format, this table is best viewed in two-page mode]

Author	Study type	Specimen	No of implants	Angulation of implants	Vertical position of implants	Implant System	Fixture	Operator	Impression level
Abdel-Azim et al. (2014)	In vitro	(partially) edentulous	4, 2	Not stated	Not stated	Straumann TL	Implant	Not stated	Abutment level
Amin et al. (2016)	In vitro	Edentulous	5	Not stated	Not stated	Straumann BL	Implant	Inexperienced	Implant level
Andriessen et al. (2014)	In vivo	Edentulous	2	Not stated	Not stated	Straumann TL	Implant	Not stated	Implant level
Bergin et al. (2013)	In vitro	Edentulous	5	Not stated	Not stated	Nobel Replace	Analog	Not stated	Implant level
Karl et al.	In vitro	Partially edentulous	2	Not stated	Not stated	Straumann TL	Implant	Not stated	Implant level
Lee et al. (2015)	In vitro	Partially edentulous	1	Not stated	Not stated	Straumann BL	Implant	Not stated	Implant level
Lin et al.	In vitro	Partially edentulous	2	Parallel; 15° 30; 45	3	Straumann TL	Analog	Not stated	Implant level
Ono et al. (2013)	In vitro	Edentulous	4	Not stated	Not stated	Nobel (Brånemark RP)	Analog	Not stated	Implant level
Papaspyridakos et al., 2016	In vitro	Edentulous	5	31, 33, 41, 43: parallel 35: 10° 45: 15°	Not stated	Straumann BL	Analog	Not stated	Implant level

Beuer, 2012; Stimmelmayer, Güth, Erdelt, Edelhoff, & Beuer, 2012); laser scanner (D250, 3Shape, Denmark) (Flügge et al., 2017); photogrammetric scanner (Imetric 3D, Switzerland) and photogrammetric technology using a digital camera (Nikon D90, NY, USA) (Bergin, Rubenstein, Mancl, Brudvik, & Raigrodski, 2013); conosopic holography (NobelProcera™ Scanner, Nobel Biocare, Sweden) (Katsoulis et al., 2013) and an optical tracking device (Micron Tracker 2, Claron Technology, Canada) (Ono et al., 2013).

One study used CBCT technology (LOC-I, ENGimage) for acquisition of implant positions (Corominas-Delgado et al., 2015). The studied intra-oral scanning devices were as follows: Trios (3Shape, Denmark) (Flügge,

Att, Metzger, & Nelson, 2016; Papaspyridakos et al., 2016; Vandeweghe et al., 2017); Cerec (Bluecam and Omnicam devices, Sirona, Germany) (Aktas et al., 2014; Amin et al., 2016; Giménez et al., 2015a,b; Giménez, Pradies et al., 2015; Vandeweghe et al., 2017); iTero (Cadent, CA, USA) (Abdel-Azim et al., 2014; Flügge et al., 2016; Giménez et al., 2014; Lee et al., 2015; Lin et al., 2015); TrueDefinition (3M Espe, USA) (Amin et al., 2016; Flügge et al., 2016; Vandeweghe et al., 2017); LavaCOS (3M Espe, USA) (Giménez et al., 2015a,b; Giménez, Pradies et al., 2015; Karl et al., 2012; Vandeweghe et al., 2017); 3D Progress (MHT) (Giménez et al., 2015a,b; Giménez, Pradies et al., 2015); and ZFX Intrascan (Zimmer) (Giménez et al., 2015a,b; Giménez, Pradies et al., 2015).



**TABLE 5** (additional columns)

Digital					Conventional					
Optical scanning device	Scan body manufacturer	Scan body features	Splinting	Powder	Tray design	Tray production	Impression copings	Impression material	Splinting	Outcomes
iTero	Not stated	Not stated	Not splinted	Powder	Closed	Custom	Transfer plastic caps	Polyvinyl siloxane		Marginal discrepancy: single-unit lower for conventional; full arch: lower for digital
Omnica TrueDef	Straumann	Cylindrical, screw retained	Not splinted	Powder/no powder	Open	Custom	Original pick-up, screw retained	Polyether	Splinted	Digital more accurate than conventional True Definition more accurate than Omnicam scanner
iTero	Straumann	Two-piece, screw-retained	Not splinted	No powder	Not stated	Not stated	Not stated	Not stated	Not stated	Digital impressions to inaccurate for production of frameworks
Digital camera	Custom	Two spheres on vertical shaft	Not splinted	No powder	Open	Not stated	Screw-retained	Not stated	Splinted	Similar accuracy of photogrammetry and conventions method
Lava COS	Straumann	Abutment	Not splinted	Powder	Open	Custom	Original pick-up, screw retained	Polyether	Not splinted	Digital as precise as conventional for fabrication of framework on implants
iTero	Straumann	Two-piece, screw-retained	-	No powder	Closed	Not stated	Not stated	Polyvinyl siloxane	Not splinted	Significant differences for digital and conventional for vertical implant position
iTero	Straumann	Two-piece, screw-retained	Not splinted	No powder	Open	Custom	Straumann screw retained	Polyvinyl siloxane	Not splinted	Digital less accurate than conventional impressions
Micron Tracker 2	Custom	Paper +titanium flags	Not splinted	No powder	Open	Custom	Original screw-retained	Polyvinyl siloxane	Splinted	Accurate acquisition of implant position with novel optical method for extraoral model scans
Trios	Straumann	Cylindrical, screw retained	Not splinted	No powder	Open	Custom	Original pick-up, screw retained	Polyvinyl siloxane	Splinted/non-splinted	Digital as accurate as conventional implant impressions

### 3.4 | Scan bodies

The majority of studies used original implant scan bodies for intraoral and extraoral optical scanning (Amin et al., 2016; Flügge et al., 2016, 2017; Katsoulis et al., 2013; Lee et al., 2015; Lin et al., 2015; Papaspyridakos et al., 2016; Stimmelmayer, Erdelt et al., 2012; Stimmelmayer, Güth et al., 2012). Besides original scan bodies, generic scan bodies (Corominas-Delgado et al., 2015; Giménez et al., 2014, 2015a,b; Giménez, Pradies et al., 2015; Vandeweghe et al., 2017) or abutments (Aktas et al., 2014; Karl et al., 2012) were used for optical scanning. Photogrammetric acquisition of implant

positions was realized with custom-made scan bodies (Bergin et al., 2013; Ono et al., 2013). The used scan body was not disclosed by Abdel-Azim et al. (2014); the retention of custom scan bodies was not disclosed by Ono et al. (2013). All other authors used screw-retained scan bodies analog to conventional impression copings (Amin et al., 2016; Bergin et al., 2013; Corominas-Delgado et al., 2015; Flügge et al., 2016, 2017; Giménez et al., 2014, 2015a,b; Giménez, Pradies et al., 2015; Karl et al., 2012; Katsoulis et al., 2013; Lee et al., 2015; Lin et al., 2015; Papaspyridakos et al., 2016; Stimmelmayer, Erdelt et al., 2012; Stimmelmayer, Güth et al., 2012; Vandeweghe et al., 2017). The most commonly used scan

bodies among all studies had a cylindrical design (Aktas et al., 2014; Amin et al., 2016; Flügge et al., 2016, 2017; Giménez et al., 2014, 2015a,b; Giménez, Pradiés et al., 2015; Karl et al., 2012; Katsoulis et al., 2013; Papaspyridakos et al., 2016; Stimmelmayer, Erdelt et al., 2012; Stimmelmayer, Güth et al., 2012; Vandeweghe et al., 2017). Original scan bodies used in two studies differed from the cylindrical design with a short lower part and an angled top part (Lee et al., 2015; Lin et al., 2015). For photogrammetric acquisition, two different designs were examined: a vertical shaft with one sphere close to the implant and another sphere at the coronal end of the shaft (Bergin et al., 2013) and scan flags manufactured from either titanium or paper with a pattern on the surface and different sizes of the flag surface (Ono et al., 2013). Scan bodies were never splinted for extraoral or intraoral scanning. The application of powder was performed in accordance with instructions by each manufacturer.

All studies on digital implant impressions and digital and conventional implant impressions are summarized in Tables 4 and 5.

### 3.5 | Conventional impressions

Conventional implant impressions were performed with the open tray method (Akalin et al., 2013; Aldosari, 2014; Aldosari et al., 2015; Amin et al., 2016; de Avila, de Matos Moraes, Castanharo, Del'Acqua, & de Assis Mollo, 2014; Bergin et al., 2013; Beyabanaki, Shamshiri, Alikhasi, & Monzavi, 2015; Buzayan, Baig, & Yunus, 2013; Di Fiore et al., 2015; Ehsani et al., 2013; Geramipannah, Sahebi, Davari, Hajimahmoudi, & Rakhshan, 2015; Ghahremanloo et al., 2017; Ghanem, Nassani, Baroudi, & Abdel Fattah, 2015; Gupta et al., 2017; Heidari et al., 2016; Lin et al., 2015; Marotti et al., 2014; Ongül et al., 2012; Ono et al., 2013; Papaspyridakos et al., 2012; Perez-Davidi et al., 2016; Pozzi et al., 2013; Pujari, Garg, & Prithviraj, 2014; Selvaraj, Dorairaj, Mohan & Simon, 2016; Vigolo, Mutinelli, Fonzi & Stellini, 2014; Vojdani, Torabi, & Ansarifard, 2015; Zen et al., 2015), the closed tray method (Abdel-Azim et al., 2014; Calesini et al., 2014; Del'acqua, de Avila, Amaral, Pinelli, & de Assis Mollo, 2012; Gökçen-Rohlig et al., 2014; Ibrahim, Fouad, Elewa, & Mustafa, 2014; Ibrahim & Ghuneim, 2013; Karl et al., 2012; Lee et al., 2015; Reddy, Prasad, Vakil, Jain, & Chowdhary, 2013) or both the open and closed tray methods for comparison of the accuracy (Al Quran et al., 2012; Alikhasi, Siadat, Beyabanaki, & Kharazifard, 2015; Alikhasi, Siadat, & Rahimian, 2015; de Avila, Barros, Del'Acqua, Castanharo, & Mollo Fde, 2013; BalaMurugan & Manimaran, 2013; Chang, Vahidi, Bae, & Lim, 2012; Haghi, Shiehzhadeh, Nakhaei, Ahrari, & Sabzevari, 2017; Hazboun, 2013; Howell et al., 2013; Karl & Palarie, 2014; Mpikos et al., 2012; Nakhaei, Madani, Moraditalab, & Haghi, 2015; Ng et al., 2014; Pera et al., 2016; Rutkunas, Sveikata, & Savickas, 2012; Sabouhi et al., 2015, 2016; Shankar et al., 2016; Shim et al., 2015; Siadat et al., 2016). Two studies did not use trays and compared stress induced by splinting two impression posts on dental implants with different splinting materials and techniques to each other (Lopes-Júnior, de Lima Lucas, Gomide, & Gomes, 2013a,b).

Impression copings were selected according to implant specifications and tray design. Pick-up impression copings for open tray

impressions, conical screw-retained impressions copings and screw-retained copings with plastic caps retained in the impression for closed tray impressions as well as Encode abutments and original implant abutments were used for conventional impressions. Pick-up copings with screw retention for open tray impression techniques were used in 23 studies. In 36 studies, the authors compared different impression copings with each other; however, screw-retained copings with plastic caps were only studied in one study and conical transfer copings were not used exclusively in any study. Two studies did not disclose the used impression copings (Papaspyridakos et al., 2012; Reddy et al., 2013).

Impression materials were polyvinylsiloxane, vinylsiloxanether, polyether or condensation silicone. Polyvinylsiloxane materials were used in 26 studies (Abdel-Azim et al., 2014; Al-Abdullah, Zandparsa, Finkelman, & Hirayama, 2013; Alikhasi, Siadat, Beyabanaki et al., 2015; Alikhasi, Siadat, & Rahimian, 2015; de Avila et al., 2013, 2014; BalaMurugan & Manimaran, 2013; Beyabanaki et al., 2015; Calesini et al., 2014; Del'acqua et al., 2012; Di Fiore et al., 2015; Ehsani et al., 2013; Geramipannah et al., 2015; Ghahremanloo et al., 2017; Heidari et al., 2016; Howell et al., 2013; Ibrahim et al., 2014; Lee et al., 2015; Lin et al., 2015; Marotti et al., 2014; Nakhaei et al., 2015; Ono et al., 2013; Pozzi et al., 2013; Sabouhi et al., 2016; Shim et al., 2015; Siadat et al., 2016; Zen et al., 2015), whereas polyether was used in 22 studies (Al Quran et al., 2012; Aldosari, 2014; Aldosari et al., 2015; Alikhasi, Bassir, & Naini, 2013; Amin et al., 2016; Ghanem et al., 2015; Hazboun, 2013; Ibrahim & Ghuneim, 2013; Karl et al., 2012; Martínez-Rus et al., 2013; Mpikos et al., 2012; Ng et al., 2014; Ongül et al., 2012; Papaspyridakos et al., 2012; Pera et al., 2016; Perez-Davidi et al., 2016; Rashidan, Alikhasi, Samadizadeh, Beyabanaki, & Kharazifard, 2012; Selvaraj et al., 2016; Stimmelmayer, Erdelt et al., 2012; Stimmelmayer, Güth et al., 2012; Tarib et al., 2012; Tsagkalidis et al., 2015; Vigolo et al., 2014), and vinylsiloxanether and condensation silicone were each used in one study (Eliasson & Ortorp, 2012). Sixteen studies compared any combination of the aforementioned impression materials (Akalin et al., 2013; Alikhasi, Siadat, Beyabanaki et al., 2015; Alikhasi, Siadat, & Rahimian, 2015; Buzayan et al., 2013; Chang et al., 2012; Ebadian, Rismanchian, Dastgheib, & Bajoghli, 2015; Gökçen-Rohlig et al., 2014; Gupta et al., 2017; Haghi et al., 2017; Karl & Palarie, 2014; Kurtulmus-Yilmaz et al., 2014; Pujari et al., 2014; Reddy et al., 2013; Rutkunas et al., 2012; Shankar et al., 2016; Vojdani et al., 2015; Wegner, Weskott, Zenginell, Rehmann, & Woestmann, 2013).

Splinting of impression copings was studied and compared with nonsplinting of impression copings in numerous studies. Thirty-two studies used nonsplinted impression copings (Akalin et al., 2013; Aldosari, 2014; Aldosari et al., 2015; Alikhasi et al., 2013; Alikhasi, Siadat, Beyabanaki et al., 2015; Alikhasi, Siadat, & Rahimian, 2015; BalaMurugan & Manimaran, 2013; Calesini et al., 2014; Ebadian et al., 2015; Ehsani et al., 2013; Eliasson & Ortorp, 2012; Geramipannah et al., 2015; Ghahremanloo et al., 2017; Gökçen-Rohlig et al., 2014; Haghi et al., 2017; Howell et al., 2013; Ibrahim et al., 2014; Karl & Palarie, 2014; Karl et al., 2012; Lee et al., 2015; Lin et al., 2015; Marotti et al., 2014; Mpikos et al., 2012; Nakhaei et al., 2015; Ng et al., 2014; Rashidan et al., 2012; Reddy et al., 2013; Sabouhi et al.,

**TABLE 6** Analysis of linear and 3D surface deviations ( $\mu\text{m}$ ) measured for conventional and digital impressions

Clinical situation	Implant distribution	Implant angulation	Conventional impression				Digital impression			
			No. of (sub-) studies	Mean	CI	Heterogeneity (%)	No. of (sub-) studies	Mean	CI	Heterogeneity (%)
Edentulous	Neighboring implants	Unknown	4	86.8	-8.4-181.9	63.3				
		Parallel	10	40.0	29.6-50.3	97.6	6	24.2	13.3-35.1	45.2
	Full arch	21-45 degrees					6	19	10.7-27.3	66.7
		Unknown	67	77.7	64.9-90.5	96.4				
	Quadrant	Parallel	62	97.1	93.2-100.9	100.0	12	51.0	28.0-74.0	69.0
		1-20 degrees	26	42.0	36.5-47.5	97.7				
		21-45 degrees	24	212.0	158.5-265.5	97.8	6	54.9	5.8-103.9	81.2
Partially edentulous	Unknown implant distribution		18	431.6	285.0-578.2	94.3				
	Neighboring implants	Parallel	7	26.7	24.0-29.5	98.7				
		1-20 degrees	20	28.7	26.3-31.2	99.0	4	11.9	4.1-19.8	82.5
		21-45 degrees	4	46.5	35.8-57.2	98.4				
	Quadrant	Parallel	7	37.1	28.7-46.5	92	1	304.0	278.6-329.4	0
		1-20 degrees	2	73.1	54.4-91.8	0	8	57.9	37.8-78.0	98.5
		21-45 degrees	1	82	40.8-123.2	0	1	158.0	102.8-213.2	0
	Unknown		4	37.1	21.4-52.8	90.1				
	Full arch	Parallel	3	31.6	9.7-53.6	45.7				
		1-20 degrees					2	21.0	1.7-40.3	0
		21-45 degrees	3	74.3	29.2-119.4	43	2	37.0	10.7-63.3	0

2015; Shim et al., 2015; Siadat et al., 2016; Vojdani et al., 2015; Wegner et al., 2013), whereas seven studies used splinted impression copings for open tray impressions (Amin et al., 2016; Bergin et al., 2013; Di Fiore et al., 2015; Gupta et al., 2017; Ono et al., 2013; Rutkunas et al., 2012; Selvaraj et al., 2016) and one study splinted conical transfer copings for closed tray impressions. Twenty-five studies compared splinted and nonsplinted impression techniques (Al-Abdullah et al., 2013; de Avila et al., 2013, 2014; Beyabanaki et al., 2015; Buzayan et al., 2013; Chang et al., 2012; Del'acqua et al., 2012; Ghanem et al., 2015; Hazboun, 2013; Heidari et al., 2016; Ibrahim & Ghuneim, 2013; Kurtulmus-Yilmaz et al., 2014; Martínez-Rus et al., 2013; Ongül et al., 2012; Papaspyridakos et al., 2012; Pera et al., 2016; Perez-Davidi et al., 2016; Pujari et al., 2014; Sabouhi et al., 2016; Shankar et al., 2016; Stimmelmayer, Erdelt et al., 2012; Stimmelmayer, Güth et al., 2012; Tarib et al., 2012; Tsagkalidis et al., 2015; Vigolo et al., 2014; Zen et al., 2015).

### 3.6 | Outcome assessment

The accuracy outcome was examined by measuring deviations between reference models and test models or by assessing the fit of frameworks on test models that were manufactured on reference models. Accuracy assessment comprised (a) measurement of linear and angular deviations or three-dimensional surface deviations, respectively, between reference models and test models; (b) measurement of marginal discrepancy between abutments and implant-supported frameworks; (c) measurement of strain after connection of implant-supported frameworks on test models.

For the assessment of linear and angular distances between implants, reference models and test models were measured with coordinate measuring machines (CMM) (Alikhasi et al., 2013; Alikhasi, Siadat, Beyabanaki et al., 2015; Alikhasi, Siadat, & Rahimian, 2015; BalaMurugan & Manimaran, 2013; Bergin et al., 2013; Beyabanaki et al., 2015; Buzayan et al., 2013; Di Fiore et al., 2015; Ebadian et al., 2015; Ehsani et al., 2013; Geramipناه et al., 2015; Ghahremanloo et al., 2017; Gupta et al., 2017; Heidari et al., 2016; Martínez-Rus et al., 2013; Mpikos et al., 2012; Nakhaei et al., 2015; Ng et al., 2014; Rashidan et al., 2012; Selvaraj et al., 2016; Shankar et al., 2016; Siadat et al., 2016; Tsagkalidis et al., 2015; Vojdani et al., 2015; Wegner et al., 2013). Other authors used microscopes (Akalin et al., 2013; Aldosari, 2014; Aldosari et al., 2015; Chang et al., 2012; Ghanem et al., 2015; Haghi et al., 2017; Ibrahim & Ghuneim, 2013), digital micrometers (Al Quran et al., 2012; Tarib et al., 2012), a profile projector (Vigolo et al., 2014) or a laser measuring machine (Eliasson & Ortorp, 2012) to measure implant positions in conventional stone casts and compare them between reference and test models. Measurements of linear distances were also performed on standardized photographs of conventional models (Hazboun, 2013; Ibrahim & Ghuneim, 2013; Rutkunas et al., 2012).

Virtual measurements of implant distances and angulations were performed after optical digitization of stone casts produced from conventional impressions (Gökçen-Rohlig et al., 2014; Howell et al., 2013; Lin et al., 2015; Ongül et al., 2012; Ono et al., 2013; Pera et al., 2016; Pozzi et al., 2013; Sabouhi et al., 2015, 2016; Shim et al., 2015;

Stimmelmayer, Erdelt et al., 2012; Stimmelmayer, Güth et al., 2012) or after performing optical impressions with various intraoral scanners (Flügge et al., 2016, 2017; Giménez et al., 2014, 2015a,b; Giménez, Pradiés et al., 2015; Stimmelmayer, Erdelt et al., 2012; Stimmelmayer, Güth et al., 2012; Vandeweghe et al., 2017).

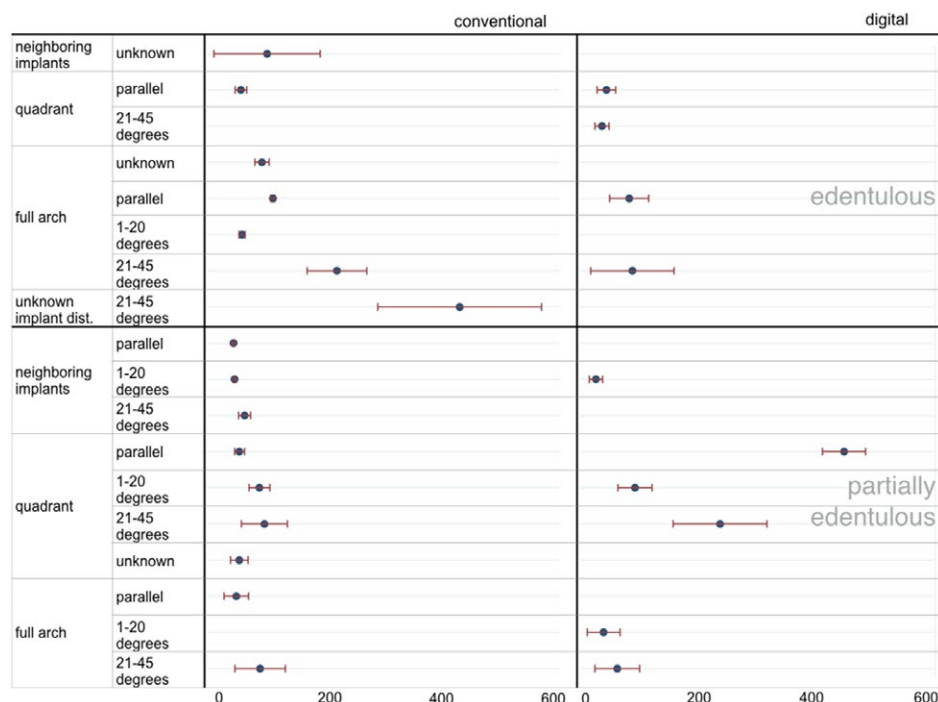
In other studies, impression accuracy was assessed with virtual measurement of three-dimensional surface deviations between scan bodies/impressions posts mounted on implants in reference models and test models (Amin et al., 2016; Calesini et al., 2014; Kurtulmus-Yilmaz et al., 2014; Lee et al., 2015; Papaspyridakos et al., 2012).

The accuracy of implant-supported frameworks produced on master models and fitted on test models was assessed using different measurement protocols. Authors used strain gauges to measure the strain in a framework after the placement on implant abutments (BalaMurugan & Manimaran, 2013; Karl & Palarie, 2014; Karl et al., 2012; Zen et al., 2015). Marginal discrepancy between abutment and framework was measured using microscopes (Abdel-Azim et al., 2014; de Avila et al., 2013, 2014; Del'acqua et al., 2012; Marotti et al., 2014; Zen et al., 2015), optical comparators (Al-Abdullah et al., 2013; Pujari et al., 2014; Reddy et al., 2013), a surface profilometer (Fernandez et al., 2013), an electron microscope (Katsoulis et al., 2013) or standardized photographs (Ono et al., 2013). The three-dimensional fit of frameworks was examined by lining of caps and measurement of lining material thickness (Aktas et al., 2014). Frameworks on implants in formalin-conserved human mandibles were assessed by probing of the gap, interpreting fit on periapical radiographs and photographs (Corominas-Delgado et al., 2015). In vivo studies assessed the gap between frameworks and abutments using periapical radiography (Perez-Davidi et al., 2016) or clinical examination using a dental probe (Pozzi et al., 2013).

### 3.7 | Meta-analysis

Seventy-nine studies of the accuracy of conventional and digital impression accuracy were included in the systematic review. Mean values and standard errors for linear and angular distances or three-dimensional surface deviations as well as marginal discrepancy and strain were included for the analysis.

Sixteen studies were excluded from meta-analysis due to differences in reporting of results in the following situations. (a). Studies stating the median values and range (Beyabanaki et al., 2015; Buzayan et al., 2013; Pera et al., 2016; Vigolo et al., 2014) or the mean values without the standard error (Andriessen et al., 2014; Calesini et al., 2014; Papaspyridakos et al., 2016). (b). Mean deviations could not be calculated and included for analysis, when authors stated absolute interimplant distances in test models without distances in reference models (Reddy et al., 2013). (c). The documentation of deviations without the measuring unit (Alikhasi, Siadat, Beyabanaki et al., 2015; Alikhasi, Siadat, & Rahimian, 2015; Mpikos et al., 2012; Shankar et al., 2016). (d). Failure of communication when email contact with the authors was attempted for clarification of methods and results (Alikhasi, Siadat, Beyabanaki et al., 2015; Alikhasi, Siadat, & Rahimian, 2015; Siadat et al., 2016). (e). Studies with clinical and radiological assessment of implant-supported frameworks in vivo (Perez-Davidi et al.,



**FIGURE 2** Forest plot of results for linear and 3D surface deviations ( $\mu\text{m}$ ) measured for conventional and digital impressions

2016) and in vitro (Corominas-Delgado et al., 2015) were not included in meta-analysis, because they did not state a numerical value for accuracy. (f). The examination of fit by measuring the thickness of lining material between framework caps and implant abutments was excluded from meta-analysis, as values measured with this method were not comparable with marginal discrepancy values (Aktas et al., 2014). Therefore, meta-analysis was performed with 63 studies.

Studies were grouped for the clinical edentulous situations (edentulous jaws, partially edentulous jaws, single-unit restorations), the distribution of implants within the jaw (neighboring implants, implants in one quadrant and implants in the complete dental arch) and the angulation of implants (parallel, 1–20 degrees and 21–45 degrees).

Linear and surface deviations (Table 6, Figure 2), angular deviations (Table 7) and marginal discrepancy (Table 8) of conventional and digital impressions are displayed.

Studies of conventional impressions mostly included edentulous conditions and implants distributed within the complete dental arch. Mean linear and surface deviations of  $97.1 \mu\text{m}$  (CI  $93.2\text{--}100.9 \mu\text{m}$ ) and angular deviations of  $2.0^\circ$  (CI  $1.6\text{--}2.0^\circ$ ) for parallel implants and  $77.7 \mu\text{m}$  (CI  $64.9\text{--}90.5 \mu\text{m}$ ) and  $0.6^\circ$  (CI  $0.4\text{--}0.7^\circ$ ) for implants with unknown angulation were reported. However, high heterogeneity of 100% and 96.4% for linear and surface deviations and 95.9% and 97.0% for angular deviations were found. High linear and surface deviations for conventional impressions were reported for implants with an unknown position in the dental arch and interimplant angulations of 21–45 degrees (mean:  $431.6 \mu\text{m}$ , CI  $285.0\text{--}578.2 \mu\text{m}$ ). Fewer studies of digital impressions of edentulous jaws with parallel implants distributed within the complete dental arch were available and resulted in linear and surface deviations of  $51 \mu\text{m}$  (CI  $28.0\text{--}74.0 \mu\text{m}$ ) and heterogeneity of 69%.

Conventional impressions of partially edentulous jaws mostly evaluated neighboring implants resulting in mean linear and surface deviations of  $28.7 \mu\text{m}$  (CI  $26.3\text{--}31.2 \mu\text{m}$ ) and mean angular deviations of  $0.2^\circ$  (CI  $0.2\text{--}0.3^\circ$ ). Fewer studies of digital impressions were available resulting in mean deviations of  $11.9 \mu\text{m}$  (CI  $4.1\text{--}19.8 \mu\text{m}$ ) and  $0.4^\circ$  (CI  $0.3\text{--}0.4^\circ$ ). High deviations were observed in a single study of digital impressions of parallel implants within one quadrant (mean:  $304.0 \mu\text{m}$ ; CI:  $278.6\text{--}320.4 \mu\text{m}$ ; mean  $1.6^\circ$ ; CI:  $1.3\text{--}1.9^\circ$ ) and angulated implants (21–45 degrees) within one quadrant (mean:  $158.0$ ; CI:  $102.8\text{--}213.2 \mu\text{m}$ ; mean:  $1.2$ , CI:  $0.8\text{--}1.7^\circ$ ) (Figure 3).

Marginal discrepancies for frameworks manufactured from conventional impressions were between  $18.3$  and  $141.5 \mu\text{m}$  in edentulous arches,  $78.1 \mu\text{m}$  in partially edentulous arches and  $24.9 \mu\text{m}$  for single units. Digital impressions resulted in mean marginal discrepancies of frameworks between  $19.0$  and  $70.2 \mu\text{m}$  in edentulous arches,  $11.9$  and  $304.0 \mu\text{m}$  in partially edentulous arches and  $66.1 \mu\text{m}$  for single units (Figure 4).

## 4 | DISCUSSION

The systematic review on the accuracy of conventional and digital implant impressions is mainly based on experimental studies with a low evidence level, except one randomized controlled clinical trial and one retrospective study focusing on the accuracy of conventional impressions. All studies of digital implant impressions published within the considered time frame (2012–2017) were experimental.

Most studies were conducted in vitro and are therefore compromised in their informative value for the clinician. Only four

**TABLE 7** Angular deviations (degrees) measured in conventional and digital impressions

Clinical situation	Implant distribution	Implant angulation	Conventional impression			Digital impression				
			No. of (sub-) studies	Mean	CI	Heterogeneity (%)	No. of (sub-) studies	Mean	CI	Heterogeneity (%)
Edentulous	Quadrant	Parallel	2	0.4	0.2-0.6	0				
		1-20 degrees	13	0.6	0.08-1.0	95.5				
		21-45 degrees	11	0.7	0.4-1.0	29.7				
	Full arch	Unknown	43	0.6	0.4-0.7	97.0				
		Parallel	20	2.0	1.6-2.4	95.9				
		1-20 degrees	16	1.4	1.1-1.8	97.8				
	Unknown implant distribution	21-45 degrees	6	2.0	0.9-3.1	99.2				
		21-45 degrees	8	5.8	4.8-6.9	41.4				
Partially edentulous	Neighboring implants	Parallel	7	0.2	0.18-0.2	99.6				
		1-20 degrees	20	0.2	0.2-0.3	99.5	4	0.4	0.3-0.4	84.5
		21-45 degrees	4	0.3	0.2-0.4	97.6				
	Quadrant	Parallel	1	0.6	0.5-0.8	0.0	1	1.6	1.3-1.9	0
		1-20 degrees	2	0.7	0.5-0.9	0.0	8	0.4	0.2-0.6	97.7
		21-45 degrees	1	0.8	0.5-1.1	0.0	1	1.2	0.8-1.7	0
	Full arch	1-20 degrees					2	0.1	0.01-0.1	0
		21-45 degrees					2	0.3	0.1-0.5	82.7

**TABLE 8** Marginal discrepancy ( $\mu\text{m}$ ) between frameworks and abutments in test models produced from conventional and digital impressions

Clinical situation	Implant distribution	Implant angulation	Conventional impression				Digital impression			
			No. of (sub-) studies	Mean	CI	Heterogeneity (%)	No. of (sub-) studies	Mean	CI	Heterogeneity (%)
Edentulous	Quadrant	Parallel	1	141.5	100.1–182.9	0	6	24.2	13.3–35.1	45.2
		1–20 degrees	4	18.3	17.5–19.1	11.9				
	Full arch	21–45 degrees					6	19	10.7–27.3	66.7
		Unknown	14	29.8	26.2–33.4	99.9	8	70.2	52.6–87.7	87.2
		Parallel	9	121.8	91.3–152.2	97.3	12	51.0	28.0–74.0	69.0
Partially edentulous	Neighboring implants	21–45 degrees					6	54.9	5.8–103.9	81.2
		1–20 degrees					4	11.9	4.1–19.8	82.5
	Quadrant	Parallel					1	304.0	278.6–329.4	0
		1–20 degrees					8	57.9	37.8–78.0	98.5
		21–45 degrees					1	158.0	102.8–213.2	0
Single unit	na	Unknown	3	78.1	64.7–91.5	86.7				
		na	4	24.9	21.9–28.0	0	4	66.1	45.9–86.3	72.6

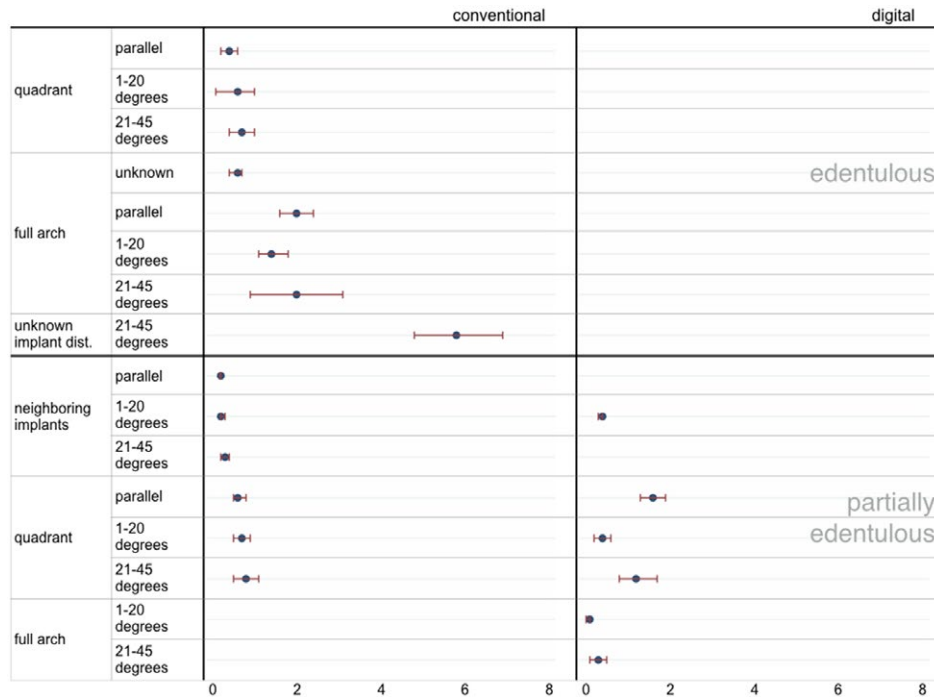
studies examined impression accuracy in vivo, thereof three studies of conventional impressions (Papaspnyridakos et al., 2012; Perez-Davidi et al., 2016; Pozzi et al., 2013) and one study of digital impressions (Andriessen et al., 2014). The major obstacle for conducting in vivo studies might be the lack of a suitable protocol to assess accuracy of intraoral impressions. The intraoral position of dental implants must be recorded and reproduced in a model using any impression technique to obtain a reference model. However, the technique to obtain a reference model is already associated with an error that introduces a bias to the assessment of the impression technique to be assessed in a study (Michalakis, Stratos, Hirayama, Pissiotis & Touloumi, 2009). The heterogeneity of results for conventional implant impressions in vitro implies that even the techniques and materials selected for conventional implant impressions (impression tray design, implant coping, impression material, splinting) influence the accuracy of the reference models.

In contrast, in vitro studies include reference models and test models that are measured with the same devices (CMM, microscope, digital micrometers, standardized photographs). The accuracy is measured as the deviation between reference and test models. Authors of in vivo studies used different assessment protocols to derive results from in vivo application of digital impressions and conventional impressions. In vivo studies often failed to report numerical values for the accuracy of implant impressions. Perez-Davidi et al. (2016) studied implant-supported frameworks and assessed the fit of frameworks on periapical radiographs. The results were stated as fit or unfit and are therefore not comparable with in vitro results. However, the informative value is high as the complete workflow including impression and framework production is considered. Further studies including reliable methods for outcome reporting are necessary. Pozzi et al. (2013) compared different conventional implant impression protocols and assessed implant failure, prosthesis failure, patient satisfaction as well as marginal bone level changes, interimplant discrepancy, chair time for fitting of frameworks, sulcus bleeding, plaque score in a randomized controlled clinical trial over 3 years. Comparable results for plaster impressions and splinted impressions with vinyl polysiloxane were documented. Comparison of the results within this systematic review was not possible due to the lack of comparable data.

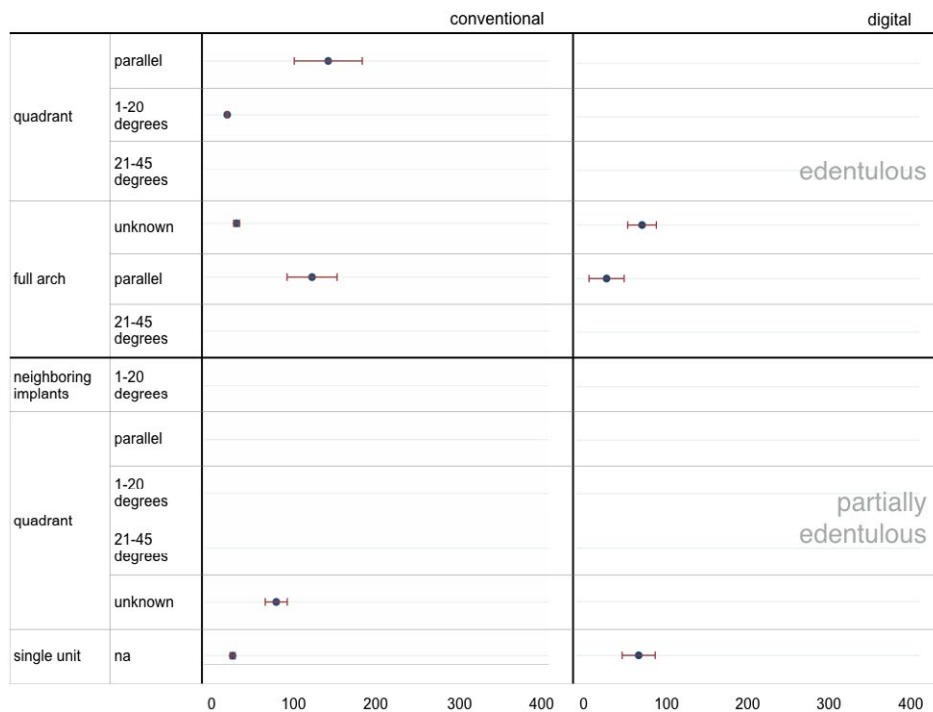
Andriessen et al. (2014) and Papaspnyridakos et al. (2012) produced a reference model using a conventional impression techniques and compared test models with reference models to obtain numerical values for impression accuracy in vivo. Papaspnyridakos et al. (2012) fabricated implant-supported prosthesis on the basis of intraoral impressions in vivo. Splinted and nonsplinted conventional impressions were compared to a reference model fabricated from a verification jig. The accuracy of the verification jig was not examined; however, the comparison of reference models and test models fabricated with two different impression techniques resulted in mean deviations between 9 and 53  $\mu\text{m}$  and were therefore comparable with impression accuracy obtained by other authors in vitro (Table 6).

Andriessen et al. examined digital intraoral impressions in vivo and compared them to reference models fabricated from conventional intraoral impressions. The intraoral optical scanning of 25 patients resulted in 21 virtual models that could be used for evaluation.





**FIGURE 3** Forest plot of results for angular deviations (degrees) measured in conventional and digital impressions



**FIGURE 4** Forest plot of results for marginal discrepancy ( $\mu\text{m}$ ) between frameworks and abutments in test models produced from conventional and digital impressions

In four patients, intraoral scanning could not produce virtual models due to wrong stitching of single images obtained with the scanner. Stitching of images is performed automatically by the scanning device; however, single images must overlap and present morphological characteristics to be stitched. The lack of intraoral characteristics for stitching in edentulous jaws implies that the use of scan body

splinting could be a very helpful tool for optical scanning of implants, especially with long distances in between implants. However, none of the studies of intraoral optical impressions examined splinting of scan bodies. The same intraoral scanning device was used in other in vitro studies, but the stitching error was not found in vitro (Abdel-Azim et al., 2014; Flügge et al., 2016; Giménez et al., 2014; Lee et al.,

2015; Lin et al., 2015). Other optical scanning devices might be associated with higher inaccuracies when used intraorally; however, there is no data on other scanning devices for implant impressions in vivo. Previous studies on intraoral optical scanning of teeth suggested that limited space within the oral cavity, saliva flow and humidity cause lower precision of scanning devices compared to extraoral application (Ender, Attin, & Mehl, 2015; Flügge et al., 2016).

Regardless of the study setting, digital impressions were examined in 11 studies, digital and conventional impressions were compared in nine studies, and conventional impressions were examined in 59 studies. Studies that documented results for deviation of reference models and test models were included in the meta-analysis. The comparison of deviations resulting from conventional and digital impressions suggests that digital implant impressions are as accurate as conventional implant impressions. Conventional impressions are more accurate for partially edentulous jaws than for completely edentulous jaws for linear and angular deviations. The influence of implant distribution and implant angulation on conventional impression accuracy could not be determined with the included studies. The heterogeneity of the results implies that specifications of each included study must be regarded for analysis. The accuracy of digital implant impressions does not differ for edentulous and partially edentulous jaws. Results are less heterogeneous; however, only a small number of studies of digital implant impressions are available for analysis.

Due to a lack of standardized value for passive fit of implant frameworks, the interpretation of results may not be based on defined requirements for impression accuracy (Kan, Rungcharassaeng, Bohsali, Goodacre, & Lang, 1999; Swallow, 2004). Framework design and fabrication as well as impression accuracy are decisive for the fit of frameworks. Marginal discrepancies of 30 up to 150  $\mu\text{m}$  between frameworks and abutments have been stated as acceptable to prevent biological and technical complications (Jemt, 1991; Klineberg & Murray, 1985). It was suggested that implants move up to 50  $\mu\text{m}$  in bone (Kim, Oh, Misch, & Wang, 2005). Therefore, a maximum misfit of 50  $\mu\text{m}$  at each implant might be considered as clinically tolerable (Andriessen et al., 2014). The suggested thresholds are already passed over prior to framework production, when reviewing the linear and angular deviations resulting from conventional and digital impressions in the included studies. Studies examining the fabrication of implant-supported frameworks on reference models and measurement of marginal gap between abutment and framework cover multiple steps in the production process of implant-supported prosthesis. Marginal discrepancies of implant-supported frameworks were below the suggested thresholds for some indications (conventional impressions: mean 21.9–141.5  $\mu\text{m}$ ; digital impressions: mean 11.9–304.0  $\mu\text{m}$ ). However, these studies were performed in vitro and a higher level of inaccuracy should be expected for in vivo impression and framework production.

The data extracted for the systematic review and meta-analysis are limited as it is mostly derived from experimental studies with low evidence level. The in vitro setup of the majority of studies reduces the informative value of the data for the clinician. The decision to use conventional or digital implant impressions should be based on available data for accuracy of each impression technique. Therefore, evidence-based data and clinical trials are necessary to

support clinical guidelines. The current literature does not provide high-quality evidence to support the selection of conventional and digital impression techniques of implants.

## 5 | CONCLUSIONS

Limited high-quality evidence is available for the study of conventional and digital implant impressions. Interpretation of results is restricted by study settings and study designs.

Some preliminary conclusions, however, can be drawn.

There is some evidence that regardless of various impression techniques, conventional implant impressions of angulated implants are significantly less accurate compared to parallel implants. Digital impressions of angulated implants, however, do not show a significantly different impression accuracy compared to parallel implants.

There is evidence showing that the scan protocol has an impact on the accuracy and precision of digital impressions. Based on the present data, this effect may not be assigned to the experience of the operator.

Clinical guidelines cannot be derived based on the presented data. Further studies focusing on the in vivo use of conventional and digital implant impressions with study protocols to reliably assess impression accuracy are needed. The performance of clinical studies and RCTs is suggested to raise evidence level for impression procedures.

## CONFLICTS OF INTEREST

The author has no conflicts of interest to declare in relation to this article.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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